# Virtual Building Construction Laboratory in Undergraduate Engineering Education

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**Abstract.** *This article describes an initial stage of development of a computer system aimed at helping undergraduate students to understand behaviour and processes occurring in construction elements. The system can be seen as an interactive book presenting and familiarising students with real laboratory tests. Apart from concentrating on the development, authors offered an overview of various computer systems so-far used in undergraduate engineering education. At the end of the article first comments and conclusions are presented.*
**Keywords.** *Virtual reality; computer simulation; engineering education.*

## INTRODUCTION

Fast development of computer technology allows usage of virtual reality (VR) as a simulation tool for different (often numerically and conceptually sophisticated) processes occurring in real world. Additionally, with well optimized programming code it is possible to simulate those processes in real time. This paper aims to present the general idea behind a computer system based on VR that will be used in a virtual building construction laboratory as a part of a training course preparing students to real structural engineering testing during their undergraduate engineering programme. The project is in its prototype stage; meaning that some basic functionality have been developed allowing staff at our institute to run preliminary tests. In this paper, we would like to share some insights and potentials of the approach on the basis of the preliminary tests.

The idea to create the virtual laboratory is based on our observation of students' rather poor performance in structural engineering laboratory. We drew the conclusion that students of the second year of a construction course often struggle to fully comprehend all aspects of structural testing conducted during laboratory classes. As a result they do not fully participate in these exercises and simply miss the most important aspect: meaningful observation of processes occurring in construction elements. Additional impediment arises from the laboratory practice so that the tests are conducted only once, hence there is no opportunity for students to repeat the observations.

Considering all aspects, the main objective of the virtual laboratory is to assist students in their preparation for real laboratory testing. We would like to stress out that our intention is not to familiarize participants with the laboratory equipment, but assisting students by means of interactive explanation and direct involvement. We think that virtual laboratory will improve students' cognitive and practical abilities.

## LITERATURE OVERVIEW

Literature reports on some cases of using ICT technology appropriately in education. One good example would be a computer system to teach students surveying concepts and practices (developed at

Purdue University in West Lafayette). This tool also includes assessment module to measure student's cognitive and practical abilities. In the core of the system, there is an Interactive Virtual Environment which is particularly suitable for science.

Interestingly some researchers (Song, Lee, 2002) proved that there is a clear advantage in using Virtual Learning Environments (VLE) such as various e-platforms allowing for instance distance learning. However, they point out that VLE rarely feature Virtual Reality (VR). Those projects are quite rare especially in undergraduate classrooms and there is need for their investigation [1]. Lack of popularity could be due to a 'bad name' that virtual reality got by being treated purely as a presentation tool not as an interactive environment. To some extend it was true. First VR systems were used just for walks through a virtual environment; the interactivity was limited to colour/texture change or to presentation of fixed variations in 3D model. On top of it the simulations were very expensive to run, as they required an advanced and powerful workstation (e.g. Silicon Graphics computers) to render high resolution pictures in real time and in an appropriate frame rate (min 25 fps, whereas for stereoscopic image – 50 fps).

A laboratory work is a very important aspect of any engineering course and it takes an essential part in undergraduate engineering education. "Doing" is the key to engineering profession. Old school approach was based on the principle of apprenticeship. Engineering education does not only require conceptual understanding (lecture and theoretical knowledge); practical knowledge is paramount. As various study show, inadequate laboratory facilities are the main reason for under-qualified graduates. Some authors argue that it is feasible to use computers in teaching laboratory work. Hashemipour, Manesh, and Bal (2009) state that computers deliver new opportunities in the laboratory by simulation, automated data acquisition, remote control of instruments, rapid data analysis and presentation. It is important to see computers as a tool to help educators in developing new curriculum (Holmes, 2007).

## UNDERGRADUATE ENGINEERING EDUCATION

Thinking about an engineer, one has no doubt, that this is a person with technical knowledge, as well as practical skills. Recalling the main protagonist from Jules Verne's novel "The Mysterious Island": engineer Cyrus Smith is a person, whose excellent pragmatic knowledge of physics laws allowed him to overcome dire situations , who can create something from nothing, and who works hand in hand with the nature to avoid waiting traps.

As teaching staff, we would like our future engineers to be productive, creative and to possess extensive knowledge and experience, so that a modern engineer will be a symbol of perseverance on a quest to acquire both understanding and practice in his chosen field.

The problems that universities are facing are often discussed on the pages of scientific publications. Recently we came across a publication by Nowakowska-Siuta, in which the author points out that one of the main predicament of higher education is the (uncontrolled) creation of new educational institutions; consequently hundreds of additional young people are enrolled on untested engineering courses as well at other disciplines.

This causes a shift in teaching priorities from quality to quantity, which can greatly affect the level of education of future technical staff. Many newly enrolled young people are already experiencing the shock of a sudden change in learning methodology and techniques, the vastness of the unfamiliar material and the steep learning curve compared to high school. And then the teaching "en masse" further minimizes the old but very valuable master - apprentice relationship, which was the main source of direct training and practice.

Another problem the universities have to contend with is the lack of time. The course agenda is stretched to maximum. Both the laboratory and theoretical classes on a particular subject are usually held only once a semester, with no opportunity to re-test and re-discuss issues. Most students have problem anticipating what stress level is to be expected in an element under a certain load or what level of applied load causes concrete cracking, or even what is a crack. Before the reform, secondary technical schools were delivering theoretical knowledge, but mostly practical professional awareness. Today we can observe the current education system moving towards a "theorization" instead "hands on" approach.

The main sources of knowledge acquisition for students are textbooks. Further development of their intuition is impossible due to low number of practical classes. A good engineer needs to back up his theoretical knowledge with a solid instinctive understanding of the subject; unfortunately, this cannot be acquired from books, and the young generation doesn't have enough practice to develop this sixth-sense.

Technical universities are faced with the difficult task of educating a modern engineer, who should not only be able to answer the theoretical question "why" but profoundly understand "why does this happen?"

## WHAT IS A VIRTUAL BUILDING CONSTRUCTION LABORATORY?

We feel that Virtual Building Construction Laboratory (VBCL) could be a possible answer to the problem of undergraduate engineering education. As a custom build computer system designated to conduct simulations of various structural engineering tests, VBCL could provide additional "hands on" experience. The laboratory is "virtual" twofold. First of all it is a numerical simulation of a building element model and complete testing process. Secondly the simulation takes place in 3 dimensional virtual reality space. The testing process will consists of three stages: (1) design and build, (2) testing and (3) analysis. The system we envision will be fully featured and our aim is to build four-dimensional environment: 3d model + time. The test simulation will be fully integrated with data analysis, as at any moment of a test a user can visualise and analyse the data obtained so far. Keeping in mind the main purpose of this virtual laboratory is educational, the system will allow the lecturer or lecturers to direct the process and the analysis to emphasize specific processes the way it suits the explanation purpose. The fourth dimension: time, will be scalable (faster-slower, pause) and movable (forward / backward). This functionality sets a very important advantage of VBCL that the environment can present processes which cannot be directly observed during traditional laboratory tests, for example: cracking mechanism or concrete adhesion. We feel this will have a positive influence on students' learning curve, will enhance and develop their imagination, perception as well as cognitive and practical abilities. Another unquestionable advantage is the possibility of conducting multiple tests. Laboratory presents a practical and empirical approach allowing students to experiment and problem-solve various tasks through practice. However, they will not be limited just to laboratory hours to conduct a specific test. Moreover, it will be possible to challenge them with a specific assignment (homework), such as: to design, produce and load (statically or dynamically) created virtual construction elements. As the last task in the assignment, students will need to analyse the obtained data and draw conclusions. This outcome could be automatically assessed allowing instant feedback.

To bring the simulations as close as possible to real tests, the processes occurring in real objects will be linked with virtual models. For this purpose a probability network will be created. Required data will be gathered from traditional structural engineering tests and will populate a designated central database. The virtual laboratory will be linked with the database through probability network to obtain specific information in order to calculate particular behaviour of a virtual model.

## APPLICATION OF VCBL

As already mentioned, the virtual laboratory will find its largest application as a didactic tool. Because of its virtual aspect as well as its wide linkablity it can serve full-time, part-time as well as for students attending e-learning courses (as an independent computer system VCBL can be plugged into any distance learning platform). Issues covered by the project and a way of conveying information may be a truly valuable teaching aid for lecturers and teachers. Through subject diversity and possibility of modelling practically any issue, virtual laboratory can be used to present specific, specialised topics e.g. for further professional development courses. Those subjects include, but are not limited to, structural mechanics, study of properties of construction materials (such as reinforced concrete, steel or timber), static and dynamic loads, vibrations and many more.

## RESEARCH AND DEVELOPMENT

Currently the project is at the initial stage (stage 1), which aims to determine whether it is visible to enhance engineering education by introducing virtual laboratory into engineering curriculum. Therefore our primary effort concentrates on research and development of those parts of the system which are necessary to determine its usability. In particular we are researching and developing the following modules: (1) element definition, (2) load/stress/cracking/deflection, (3) interaction and user interface, (4) visualisation, (5) e-platform.

At this stage, we focus on simple RC elements (such as simply supported and fixed beams, cantilevers) which are defined by the following characteristics: geometry, material properties (concrete strength, aggregate type, compaction, reinforcement type). The second module will calculate element's behaviour under certain load. The system will visualise stress state in the element, cracks and deflection (according to reinforce concrete theory and Eurocode 2). In further development this module will be linked with behaviour of real elements observed during actual structural engineering tests.

Stage 1 will be completed with pilot tests. It is planned to divide second year students into two groups. Both groups will attend classes in traditional laboratory, however only one group will be given introduction by means of the proposed virtual laboratory. At the end of the class students' knowledge and understanding of the conducted traditional structural tests will be assessed. Additionally, students involved in proposed virtual laboratory will have to complete an evaluation questionnaire, which shall help to determine usability, problems encountered, ambiguities and errors in the proposed approach.

Once updated and improved, the system will be connected to university's e-learning platform for further evaluation as lecturers' aid and as student's individual learning tool.

It is planned to split research and development of module 3 (interaction and user interface) into two directions. The first will use traditional input methods (mouse and keyboard) and standard computer (laptop or PC). As for the second we planned to develop a gesture recognition module, which should be used instead of traditional pointing devices. In this way it will be possible to use large scale displays (e.g. projection wall). It is expected that this arrangement will set the virtual laboratory in to a more realistic scenario and will allow handling of the system's functionality in front of a large group of students.

## FIRST CONCLUSIONS AND COMMENTS

As pointed out by Hashemipour, Manesh, and Bal (2009), there are clear advantages in using VR technology for educational purpose. For example for testing and solving problems in a virtual world, hence avoiding costly mistakes in operation of expensive and often dangerous equipment. Researchers point out that despite the advantages, there are not many systems based on VR and even less of them are reported in the literature. We feel that it is due to the fact that commercial applications lack the educational edge and building institutes often do not have qualified staff to design, research and develop bespoke computer systems. Therefore, we feel that our effort in creating such a tool will be beneficial not only to the students and staff of our institute, but to many more around world.

On-going research and development requires continuing testing. So far, some staff members at out institute have been involved in those tests, which show that virtual reality is the right choice for the environment of our virtual laboratory.

Prepared and tested interactive and to-some-degree realistic RC element models allow to observe element composition, stress state and internal forces that occur in those elements under certain load. It helps that as in a real laboratory a user can freely walk around and investigate the tested elements from any location.

Still, we struggle with user interface, as it is not obvious how it should be designed to allow instantaneous understanding of the system itself as well as the tasks laid in front of the students. We aim at minimising the learning effort required to operate VCBL.

The tests show that it is necessary to appropriately determine the importance and the number of start-up parameters. There is a high risk that students will not understand their task if there are too many input parameters or if the analysis include too many directions. In other words, it is paramount to adjust each part of the test process to level of knowledge of students involved in the exercise.

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